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Surface Sediments of the Nazca Plate[1]

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ABSTRACT: A new surface sediment distribution map of the southeast Pacific Ocean has been compiled from approximately 800 existing samples. Ridge sediments are characterized by calcareous ooze; deep ocean basin sediments by clay; trench sediments by mud; and continental margin sediments by mud or material of sand size or larger. Siliceous oozes are generally absent largely because of dilution by calcareous material near the equator and terrigenous material near the continent, and because of dissolution in the water column and on the sea floor. Some sediments on the East Pacific Rise and in the Bauer Depression are markedly enriched in iron and manganese, whereas, in other areas, concentrations of transition metals are confined to nodules. Organic carbon values in bottom sediments bear a direct relationship to the productivity of the overlying surface waters, and range up to 6.9 percent in a strongly upwelling area. Pyroclastic material is more widespread off Peru than Chile. This may be due to easterly upper trophosphere winds over Peru and westerly upper trophosphere winds over Chile.

THE NAZCA PLATE—bounded by the East Pacific Rise, the Chile Ridge, the Galápagos Rift Zone, and the Peru-Chile Trench—is an ideal area in which to study some of the factors that influence the composition of marine sediments. There are considerable ranges in the productivity of the surface waters, the speed and direction of dispersal mechanisms, and in the relief of the sea floor and the adjacent continent. There are also large latitudinal variations in continental climate, runoff, and erosion rates.

The primary objective of this paper is to determine the surface sediment distribution on the Nazca Plate and vicinity and to relate it to the factors which influence that distribution, such as the atmospheric and oceanic circulation patterns, biologic productivity, and terrigenous source areas. The resulting surface sediment map will provide a basis for future studies of the historical development of the Nazca Plate. The map, as well as pertinent sedimentological details will be discussed by physiographic province.

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SOURCES OF DATA

In May 1970, Oregon State University, the University of Hawaii (Hawaii Institute of Geophysics), and the National Oceanic and Atmospheric Administration (Pacific Oceanographic Laboratories), jointly began a geophysical, geological, and geochemical investigation of the Nazca oceanic plate and its interaction with the South American continental block. The program is sponsored by the International Decade of Ocean Exploration (IDOE). About 100 cores were taken on the Nazca Plate by Oregon State from January to March 1972. Previously published data, unpublished core descriptions, and the preliminary results of the 1972 cruise data are used in the study.

Altogether, nearly 800 core descriptions from many institutions were used to compile Figure 2; about 700 of these were from the Sediment Data Bank of the Scripps Institution of Oceanography. Problems with the coding and interpretation of the data from various institutions originally deposited in the bank are discussed by Frazer and others (1972). Bottom sample locations appear in Figure 1.

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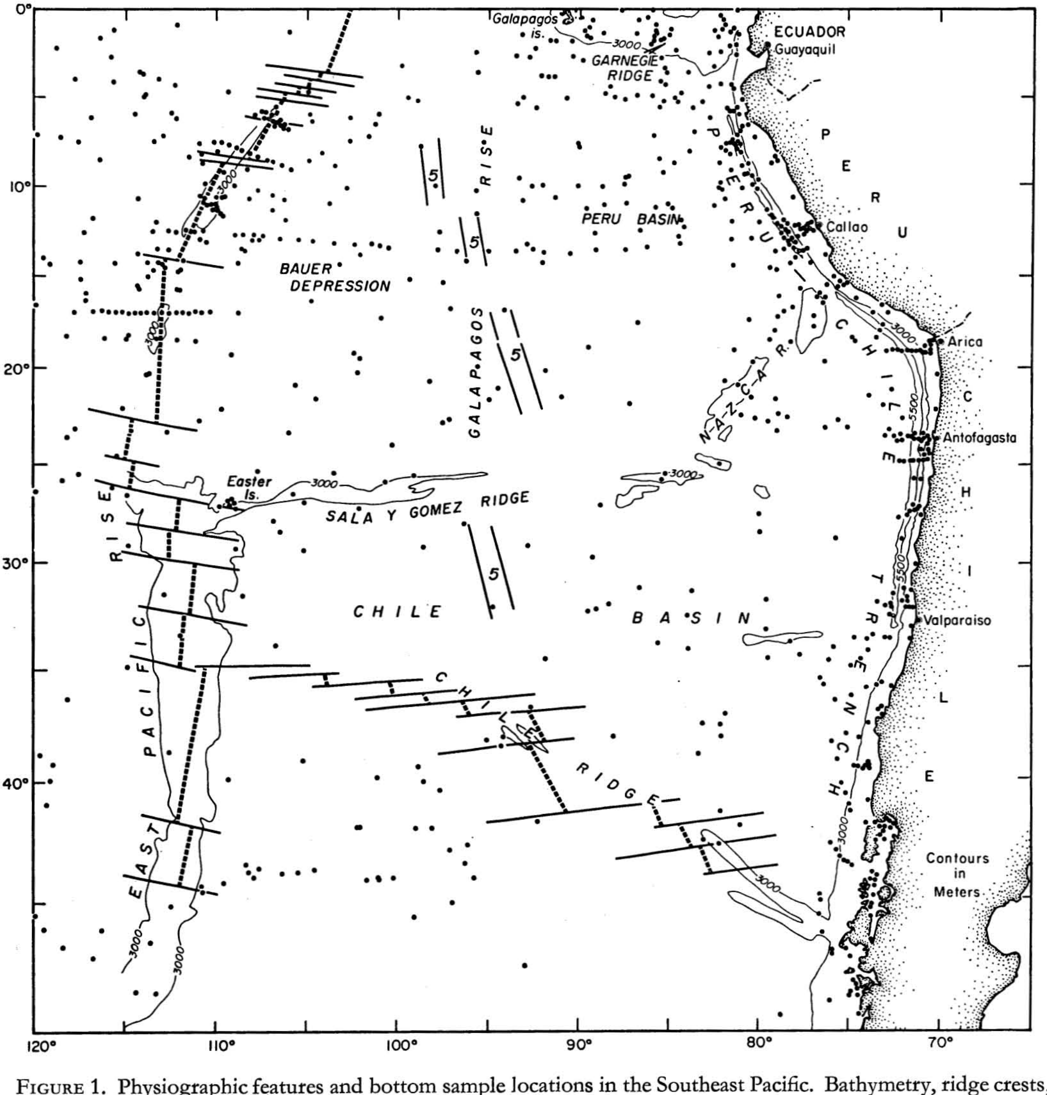

FIGURE 1. Physiographic features and bottom sample locations in the Southeast Pacific. Bathymetry, ridge crests, fracture zones, and anomaly 5 (fossil ridge) from Herron (1972). Galápagos Rise crest from Menard, Chase, and Smith (1964).

TERMINOLOGY

Definition of Sediment Types

The surface sediments of the Southeast Pacific have been classified into seven main categories (Table 1, Figure 2): (1) mud, (2) clay, (3) calcareous ooze, (4) siliceous ooze, (5) sediments of sand size or larger, (6) manganese nodules, and (7) volcanic ash. This very general sediment classification scheme was chosen pending further refinement of the sediment types by detailed sampling and petrologic work.

Of the seven sediment categories, the distribution of volcanic ash may be more extensive than indicated on the map because individual investigators may or may not have been looking for volcanic debris and/or they failed to report it. Where more than one sediment type occurs in a particular area, more than one symbol is superimposed on the map.

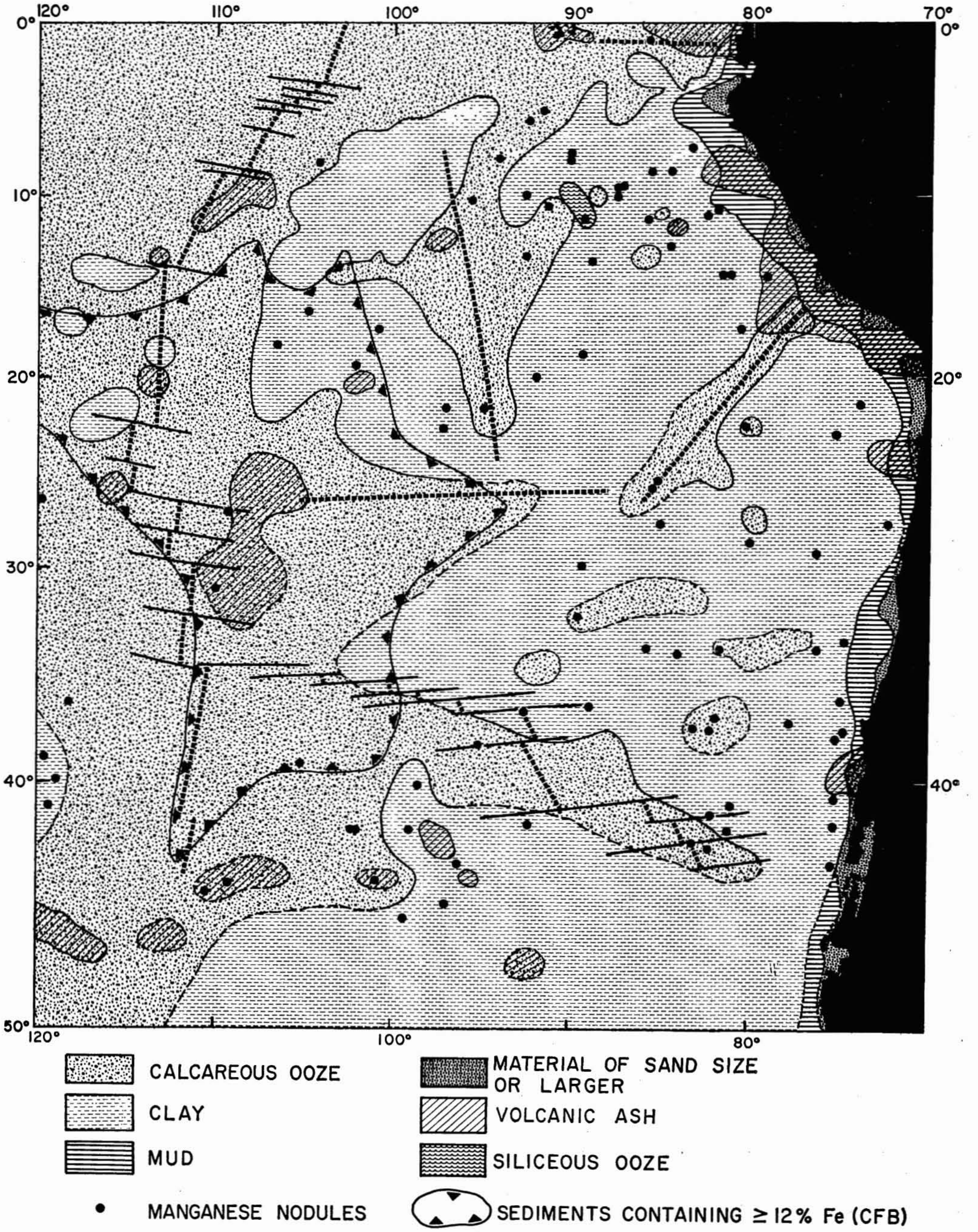

FIGURE 2. Surface sediments of the Nazca Plate. Areas where sediments exceed 12-percent Fe (CFB, carbonate free basis) after Böstrom (1970).

TABLE 1

CLASSIFICATION OF SEDIMENT TYPES

SEDIMENT TYPE	DESCRIPTION
Mud	unconsolidated, generally fine-grained, terrigenous material, including both silt and clay-size particles, diatomaceous mud, calcareous mud, siliceous mud, and sandy mud
Clay	unconsolidated fine-grained material, mostly less than 4 μm in diameter, including red (brown) clay, calcareous clay, metalliferous clay, siliceous clay, diatomaceous clay, and silty clay; usually a pelagic sediment, but more likely a hemipelagic sediment when silty
Calcareous Ooze	material containing at lease 30-percent calcium carbonate, without regard to grain size, including globigerina ooze, foraminiferal ooze, calcareous nannofossil ooze, marl ooze, chalk, coral, shell sand, and foraminiferal sand; may contain minor amounts of siliceous microfossils
Siliceous Ooze	sediments containing at least 30-percent amorphous silica, including radiolarian ooze and diatomaceous ooze
Manganese Nodules	occurrence of manganiferous concretions, not including micronodules
Sediments of Sand Size or Larger	coarse-grained terrigenous sediments greater than 62 μm in diameter, not including manganese nodules or calcareous sands, but including glacial erratics, silty sand, muddy sand, and clayey sand
Volcanic Ash	fine-grained (< 4 mm diameter), pyroclastic or hyaloclastic material, such as clear to brown colored glass shards, generally found to be common or abundant on a carbonate-free basis; does not include basaltic rocks

Physiographic Features

In this paper, the term "Southeast Pacific" will refer to the region of the Pacific Ocean between the west coast of South America and 120° W longitude, and between the equator and 50° S latitude. This area includes most of the Nazca Plate as defined by Herron (1972). The "Peru Basin" and the "Chile Basin" are new terms referring to two of the three major basins in the Southeast Pacific (Figure 1). The third major basin, the "Bauer Depression," is named after the nearby "Bauer Deep" reported by Revelle (1944). The Galápagos Rise was named by Menard, Chase, and Smith (1964).

PHYSIOGRAPHIC DISTRIBUTION OF SEDIMENT TYPES

Ridge Sediments

Surface sediments from oceanic ridges in the Southeast Pacific are composed chiefly of calcareous oozes (Figure 2, Table 2). These sediments, which sometimes have calcium carbonate contents as high as 90–93 percent, consist mostly of coccoliths and the tests of planktonic foraminifera. The noncarbonate sediment fraction on the seismically active East Pacific Rise differs from the noncarbonate sediment fraction found on aseismic ridges (Nazca Ridge, Carnegie Ridge, Sala y Gomez Ridge, and Galápagos Rise). Surface sediments on the crest and flanks of the East Pacific Rise are unusually rich in metal oxides and hydroxides (Böstrom and Peterson 1966, 1969; Cronan 1969; Böstrom 1970; Dasch, Dymond, and Heath 1971), whereas concentrations of metals on aseismic ridges are restricted to manganese nodules. Data on the metal content of sediments on the Chile Ridge are lacking, though a few manganese nodules have been found there. Sediments containing more than 12-percent Fe (CFB, carbonate-free basis) are found on the East Pacific Rise and in the Bauer Depression (Figure 2).

Montmorillonite is the most abundant clay mineral (< 2 μm fraction) in ridge sediments, which reflects the relatively high input of volcanic material from local sources in the Southeast Pacific (Peterson and Griffin 1964; Griffin, Windom, and Goldberg 1968). In general, the ratio of chlorite, kaolinite, and illite to montmorillonite in ridge sediments

TABLE 2

SUMMARY OF PHYSIOGRAPHIC DISTRIBUTION OF SEDIMENT PROPERTIES

PROPERTY	PROVINCE: RIDGES	BASINS	TRENCH	MARGIN
General Composition	calcareous ooze	clay	mud	varies
Grain size	clay to silt	clay	varies, mostly silty clay	varies, sands to silty clay
Clay Minerals	montmorillonite	smectites	varies	varies
Quartz (%)	low	low	moderate	moderate to high
Organic Carbon (%)	low	low	moderate to high	high
Calcium Carbonate (%)	high	low	low	low to moderate
Amorphous Silica (%)	low	low	moderate	low
Volcanic Ash (%)	moderate to high	low to moderate	moderate to high	moderate to high
Authigenic Minerals	manganese nodules, barite, phillipsite	manganese nodules, phillipsite	—	phosphorite
Sedimentation Rates	low to moderate	low	moderate to high	moderate to high

increases toward the South American continent (Griffin, Windom, and Goldberg 1968).

Several minor constituents of ridge sediments are also associated with deep-sea volcanism. The zeolite phillipsite, originating in the reaction of seawater with fine hyaloclastic grains, makes up to 10 percent (CFB) of some East Pacific Rise and Sala y Gomez Ridge sediments and up to 50 percent (CFB) of Chile Ridge sediments, yet it is much less abundant on other ridges (Bonatti 1970). A zone of high barite concentrations (up to 10 percent, CFB) also follows the East Pacific Rise crest (Arrhenius and Bonatti 1965). Basaltic ash is present along the East Pacific Rise and around the Galápagos Islands and Easter Island, whereas more silicic volcanic glass shards of continental origin are found on the eastern end of the Carnegie Ridge and on the northeastern end of the Nazca Ridge.

The main biogenic constituent of ridge sediments is calcareous tests; the percentage of amorphous silica on oceanic ridges in the Southeast Pacific is less than 1 percent (Lisitzin 1970). Organic carbon contents are also low (generally less than 0.5 percent), but increase to about 1 percent near the Carnegie Ridge (Lisitzin 1972) and to about 2 percent on the northeastern end of the Nazca Ridge (Rosato 1974).

Sedimentation rates (Table 3) range from 3 to 15 mm/1,000 yr on the East Pacific Rise. Rates of 6.9 and 6.1 mm/1,000 yr were measured for the Nazca Ridge (Blackman and Somayajulu 1966).

Deep Ocean Basin Sediments

Surface sediments from the major basins between oceanic ridges consist predominantly of clay (Figure 2, Table 2), which accumulates at a low rate (1–10 mm/1,000 yr; Table 3; Lisitzin 1972). Homogeneous, light to dark brown (depending in part on the percentage of calcareous microfossils present), metalliferous sediments are found in the Bauer Depression. Brown-colored clays are also found in the Chile Basin and the Peru Basin, but they are not as iron-rich as Bauer Depression sediments (Böstrom 1970). The metalliferous sediments of the Bauer Depression are similar to sediments found on the East Pacific Rise crest; they contain manganese micronodules, hydrated amorphous iron aggregates, and clay minerals of the smectite group (Dasch, Dymond, and Heath 1971). Manganese nodules and brown to gray or greenish gray colored clays and muds are more common in the Peru Basin and in the eastern portion of the Chile Basin than in the deeper parts of the basins to the west. Near the

TABLE 3

SEDIMENTATION RATE DETERMINATIONS IN THE SOUTHEAST PACIFIC

CORE	LATITUDE (S)	LONGITUDE (W)	RATE (mm/ 1,000 YR)	METHOD	REFERENCE
V19-61	16° 57′	116° 18′	7.0	Th^{230} excess	Bender et al. (1971)
V19-54	17° 02′	113° 54′	15.0	Th^{230} excess	Bender et al. (1971)
DWBG 114	18° 20′	79° 21′	6.1	Io:Th	Blackman and Somayajulu (1966)
DWBG 98C	20° 49′	81° 08′	6.9	Io:Th	Blackman and Somayajulu (1966)
RC9-99	24° 36′	115° 27′	7.0	paleomagnetism	Glass et al. (1967)
RC8-93	29° 22′	105° 14′	5.0	paleomagnetism	Glass et al. (1967)
RC8-93	29° 22′	105° 14′	3.5	paleomagnetism and Th^{230} excess	Ku, Broecker and Opdyke (1968)
RC8-93	29° 22′	105° 14′	3.6*	paleomagnetism	Ericson and Wollin (1970)
RC8-94	27° 17′	102° 05′	1.8*	paleomagnetism	Ericson and Wollin (1970)
RC8-92	31° 33′	108° 30′	2.9*	paleomagnetism	Ericson and Wollin (1970)
V17-50	34° 30′	74° 19′	3.4†	pollen spectra	Groot and Groot (1966)
DWHG 49	42° 02′	98° 01′	0.4§	Io:Th	Goldberg and Koide (1962)
E20-18	44° 23′	111° 20′	1.0‡	Th^{230} excess	Geitzenauer (1972)
E21-14	49° 02′	120° 05′	0.9‡	Th^{230} excess	Geitzenauer (1972)

* Rate calculated with data cited in reference and averaged over last 700,000 years.

† Rate calculated with data cited in reference and averaged over Quaternary period, assuming 1.8 million years' duration.

‡ Rate calculated with data cited in reference and averaged over last 300,000 years.

§ Carbonate-free basis.

eastern edge of the Nazca Plate, where it enters the trench, greenish gray to olive green muds predominate, particularly off the coast of Peru. Calcareous ooze is generally absent from the deeper parts of the basins (Kulm et al. 1974, Rosato 1974), which may lie between 4,000 and 4,500 m.

Montmorillonite is the dominant clay mineral (Peterson and Griffin 1964), but the proportions of chlorite, kaolinite, and illite in Peru Basin and Chile Basin sediments increase toward the continent (Griffin, Windom, and Goldberg 1968).

Chile Basin sediments contain up to 50-percent (CFB) phillipsite, Bauer Depression sediments up to 10-percent phillipsite, and Peru Basin sediments very little phillipsite (Bonatti 1963). Pyroclastic material, however, has rarely been reported in these areas, except in the vicinity of the Peru-Chile Trench, where most of the ash is colorless. As on oceanic ridges, the amorphous silica content of deep ocean basin sediments is $<$ 1 percent (Lisitzin 1970), except near 10° S, 90° W, where two cores of siliceous ooze were recovered (Figure 2). Organic carbon contents range up to 0.5 percent, with higher values found toward the equator and the continent (Lisitzin 1972, figure 3).

Trench Sediments

The Peru-Chile Trench sediments are texturally and compositionally heterogeneous (Figure 2, Table 2). Surface sediments consist of olive green or brown to greenish gray mud, with various proportions of clay and silt. Sand-size material also has been reported in the trench (Zen 1959, Bandy and Rodolfo 1964); some of this material is foraminiferal sand. Trask (1961) showed that the median diameter of surface sediments in the trench between 10° and 25° S is between 2 and 8 μm. Sorting is poor in most samples. Graded bedding, cross laminations, and parallel laminations were observed by Zen (1959) in a number of gravity cores.

The mineralogy of sediments from the Peru-Chile Trench area has been semiquantitatively studied by Schmalz (1958), Peterson and Goldberg (1962), Griffin, Windom, and Goldberg (1968), and Rosato (1974). Kaolinite and illite are more abundant in the trench, especially off Arica, than in the deep ocean basins to the west.

In the trench area, pyroclastic material is found north of about 20° S, at about 24° and 40° S (Figure 2). Both clear and brown-colored volcanic glass shards, in various stages of devitrification, were described in several cores (Worzel 1959, Zen 1959, Bandy and Rodolfo 1964). Quartz is more abundant in trench sediments (Zen 1959) than on the Nazca Plate; a few cores had up to 16-percent (CFB) quartz (Bonatti 1963).

Although diatoms, silicoflagellates, and radiolaria are common in sediments of the trench area (Fisher 1958, Bandy and Rodolfo 1964, Funnel 1970, Lisitzin 1971, Riedel 1971), amorphous silica generally makes up $<$ 1 percent of surface sediment, except between 8° and 15° S and between 29° and 36° S, where it ranges from 1 to 10 percent (Lisitzin 1970). Siliceous microfossils are more abundant than calcareous ones in sediments below about 3,600 m (Bandy and Rodolfo 1964; Kulm et al. 1974). Below about 3,300 m, the average calcium carbonate content of trench sediments is about 3.0 percent (Bandy and Rodolfo 1964). The organic carbon content is quite high, ranging between 1 and 5.6 percent, but it is usually not as high as on the adjacent continental margin.

Sedimentation rates are quite variable and range from 10 to 30 mm/1,000 yr (Lisitzin 1972).

Continental Margin Sediments

Surface sediments of the continental margin off Peru and Chile are also texturally and compositionally heterogeneous. Brownish green to grayish green diatomaceous muds as well as material of sand size or larger are common (Figure 2 and Table 2). Between 10° and 25° S, the median grain size ranges from 2 to 16 μm, tending to decrease seaward, and the degree of sorting varies considerably (Trask 1961).

Clay minerals are similar to those found in trench (Rosato 1974). Clear and brown-colored volcanic glass shards are abundant and dispersed in sediment cores taken from the margin, especially between Callao and Arica. Quartz is abundant (Zen 1959), and may constitute up to 16 percent (CFB) of the sediments north of about 30° S (Bonatti 1963). Phosphorite deposits may occur on the continental margin along the entire west coast of South America (McKelvey 1967; McKelvey and Wang 1969; Kolodny and Kaplan 1970; and Veeh, Burnett, and Soutar 1973).

Siliceous microfossils (diatoms in particular) are common in margin sediments off the west coast of South America (Agassiz 1906, Revelle 1944, Fisher 1958). Though quantitative measurements of the amorphous silica content are rare, Lisitzin (1970) indicated concentrations of less than 1 percent in margin sediments. Calcium carbonate contents range from about 1 to about 50 percent; highest values tend to occur closer to shore, where shell fragments are common (Zen 1959, Trask 1961, Bandy and Rodolfo 1964). On the continental slope, calcium carbonate occurs as calcareous microfossils (Bandy and Rodolfo 1964, Kulm et al. 1974).

Organic carbon contents are extremely high for the open ocean and tend to decrease with increasing distance from shore, but bear no simple relation to depth (Figure 3). The highest values (6.9 percent) occur on the continental margin between 7° and 16° S (Bandy and Rodolfo 1964, Rowe 1971, Romankevich 1972) and lie below the upwelling area (Figure 3). Although the method of analysis varies, the organic carbon contents of sediments off Peru apparently are higher than off northern Chile.

Sedimentation rates on the continental margin are comparable to rates in the trench (10 to 30 mm/1,000 yr; Lisitzin 1972). Higher rates probably exist to the south of about 32° S, where rainfall and runoff increase with increasing latitude (Scholl et al. 1970).

DISCUSSION

Organic Carbon

Trask (1939) and Gross et al. (1972) have discussed the various factors governing the amount of organic carbon in sediments. Productivity seems to be the most important factor controlling the organic carbon values in the sediments along the west coast of South America. Estimates of the productivity in the Southeast Pacific have been made by Fosbergh

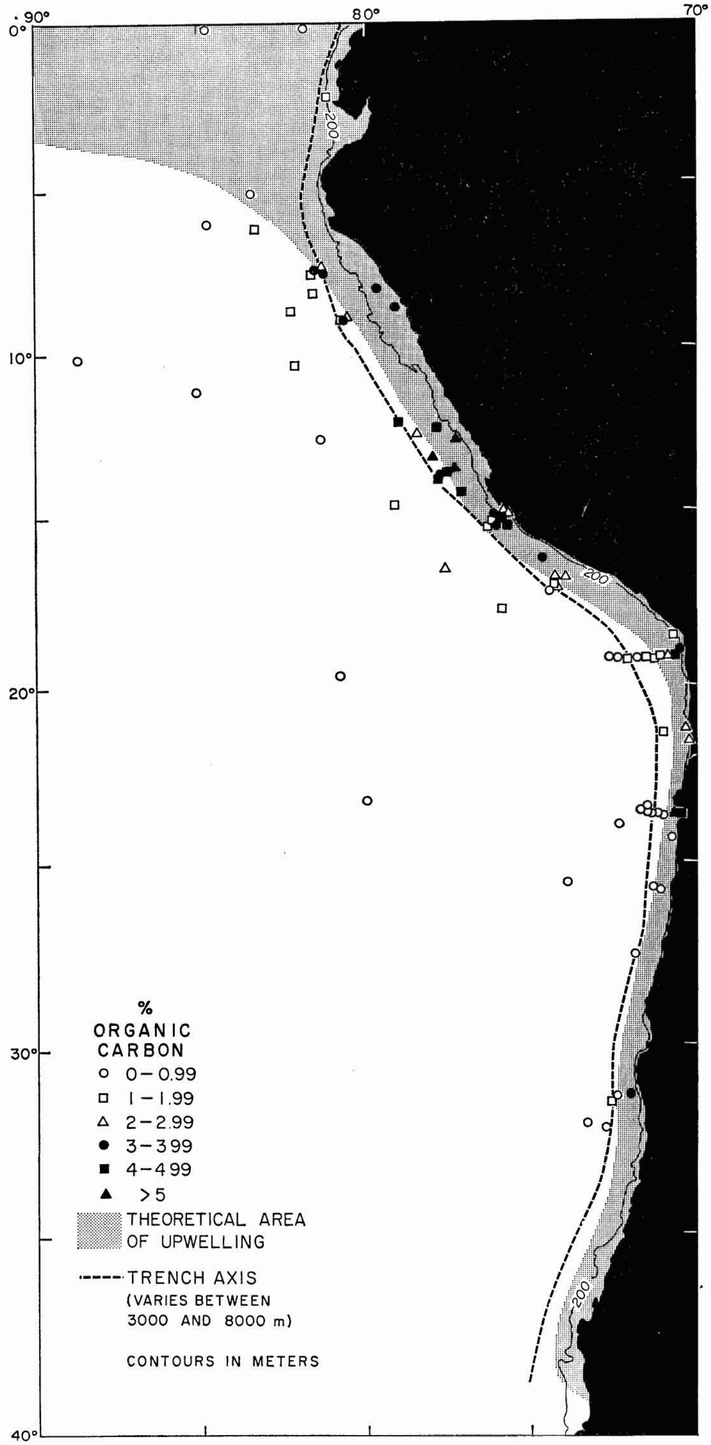

FIGURE 3. Organic carbon distribution. Data from Trask (1961), Bandy and Rodolfo (1964), Rowe (1971), Romankevich (1972), and unpublished pilot studies of cruise YALOC-71 (Oregon State University). Organic carbon values from OSU were determined with a LECO induction furnace by the method of Gross et al. (1972). Theoretical area of upwelling after Yoshida (1967). Bathymetry after Scholl et al. (1970), and T. E. Chase (unpublished map).

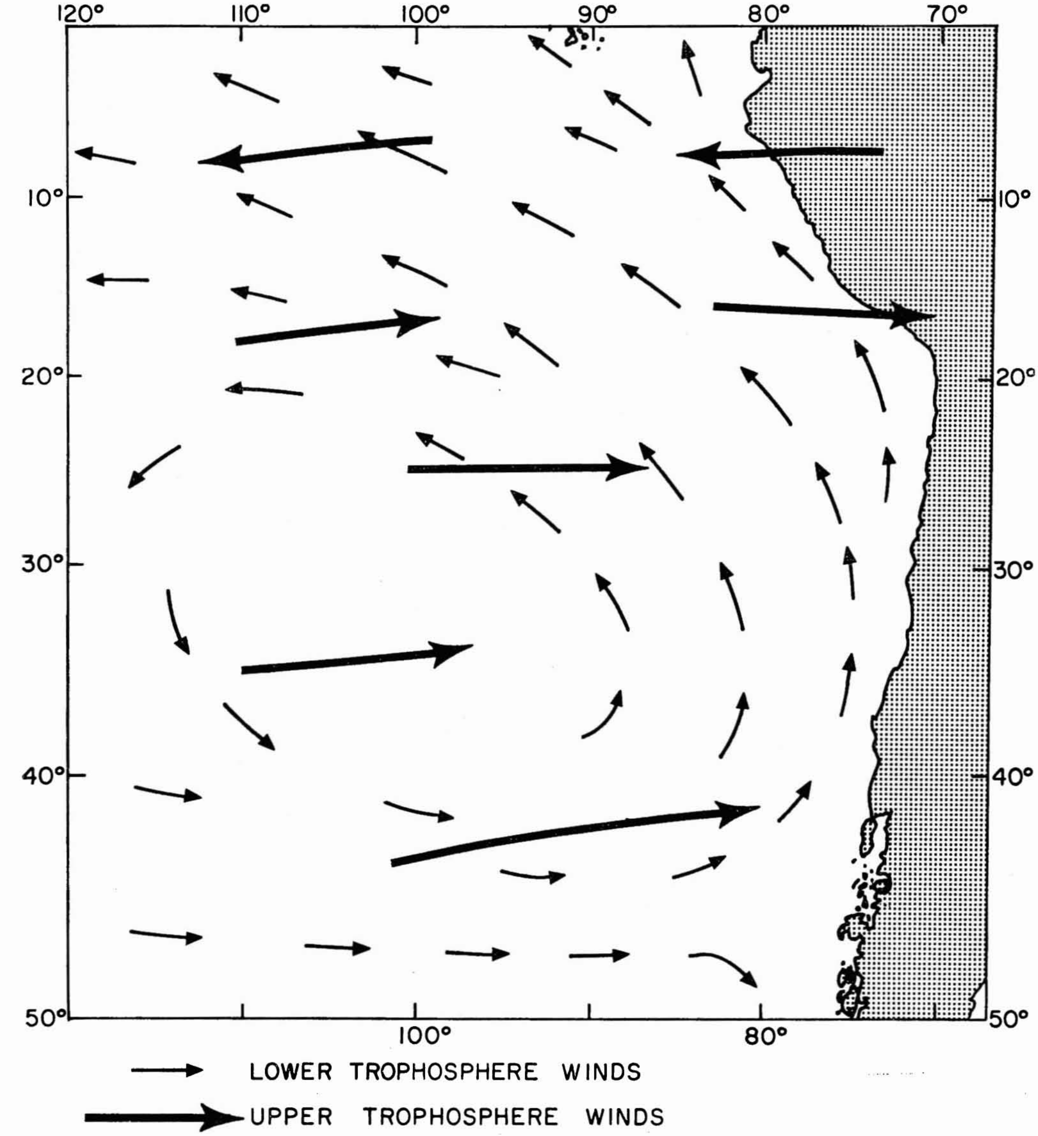

FIGURE 4. Atmospheric circulation pattern. Lower trophospheric winds after U.S. Navy Hydrographic Office (1955) and U.S. Navy (1959). Upper trophospheric winds after Rumney (1968).

and Joseph (1963), El-Sayed (1970), Beklemishev (1971), and Stevenson, Guillen, and De Ycaza (1970). The areas of high productivity are characterized by low dissolved oxygen concentrations, which would inhibit the destruction of organic carbon (Bordovskiy 1965*a*, *b*). An oxygen minimum and currents (the southward-flowing Peru Countercurrent and the Peru Undercurrent) containing low concentrations of dissolved oxygen (< 0.5 ml/liter) are clearly shown in the zonal cross sections at 27° S (Reid 1965) and between 5° and 28° S by Wyrtki (1966), and in profiles shown by Wooster and Gilmartin (1961) and White (1971). Wyrtki (1967) and Enfield (1970) have shown that the oxygen minimum impinges on the sea floor on part of the Peruvian continental margin.

Judged from both the very high amount of organic matter produced and the subsequent vertical zonation of dissolved oxygen, organic matter would tend to be preserved on the continental margin. Where the productivity is greatest, on the continental margin off Peru between 7° and 16° S, the surface waters have the highest nutrient concentrations and the highest rates of phytoplankton production, the water column has the highest oxygen concentration gradients, and the sediments have the highest percentage of organic carbon. Farther from shore, away from the area of upwelling, the water is much less productive in the euphotic zone and has a higher dissolved oxygen content at most levels. A similar conclusion was reached by Romankevich (1972), and similar relationships were noted by Gross et al. (1972) in the Northeast Pacific.

Effect of Atmospheric Circulation on Volcanic Ash Distribution

The generalized atmospheric circulation pattern for the Southeast Pacific is shown in Figure 4. Lower trophospheric winds (below about 10 km) in this area follow a counterclockwise pattern around the subtropical high pressure cell whose position varies little throughout the year (Lamb 1965, Rumney 1968). Off the coast of Peru and Chile, surface winds are more variable and diurnal wind fluctuations are common (Craig 1968; McGinnes, Goldman, and Paylore 1968). Much less is known about the winds aloft. Upper trophosphere winds (between about 10 and 17 km) are dominantly zonal (Heastie and Stephenson 1969, Lamb 1970).

The atmospheric circulation patterns are important to this discussion because marine sediments can be made up of significant amounts of eolian material, particularly in areas of low sedimentation rates; and because sediments, by their textural character, can reflect wind directions. For example, Windom (1969) has analyzed some Southeast Pacific cores from the East Pacific Rise (cores 62 to 65 at about 42° S) in an area of low sedimentation rate and found that material transported in the eastward-flowing trophospheric winds makes up an average of 41 percent of the $< 2\ \mu m$ fraction. The high quartz contents and the high illite contents off Arica are possibly due to the westward eolian transport of the products of desert weathering.

Perhaps the best picture at this time of the relationship between atmospheric circulation and sediment composition in the Southeast Pacific is provided by the distribution of volcanic ash shown in Figure 2. Basaltic volcanic glass shards extend westward of the Galápagos Islands, paralleling the lower trophospheric wind direction (Kowsmann 1973). Local submarine sources probably supply the volcanic ash near the East Pacific Rise. Although evidence of Cenozoic volcanism can be found along the entire length of the Andes, sediments containing pyroclastic material occur in a narrow belt along the coast north of about 20° S. According to the zonal cross sections of wind direction drawn by Heastie and Stephenson (1969) and shown in Figure 4, tephra expelled by Andean volcanoes into the upper trophosphere south of about 20° S would be transported to the east; north of this latitude it would travel to the west. At lower elevations of atmospheric injection, tephra might follow the counterclockwise gyre shown in Figure 4. Both levels of transport are likely, because Eaton (1963) found that about 70 percent of volcanic cloud elevations were below 9 km. Eastward transport of pyroclastic debris from a recent Chilean volcano (Eaton 1963), the distribution of atmospheric dust off the west coast of South America (Arrhenius 1963, Prospero and Bonatti 1969), and the distribution of volcanic ash in surface sediments off the coast of Peru, west of the Galápagos Islands and between 40° and 50° S on the East Pacific Rise, support this contention. On the other hand, volcanism may have been more widespread, intense, or recent north of latitude 20° S and thus may have provided more pyroclastic material to the surface sediments off Peru than off Chile.

SUMMARY

Sediments on oceanic ridges on the Nazca Plate are characterized by foram-nannofossil ooze and subordinate amounts of volcanic ash, locally and continentally derived clay minerals,

manganese nodules, or micronodules, and low percentages (< 1 percent) of organic carbon and amorphous silica. Deep ocean basins within the Nazca Plate are characterized by homogeneous, brown pelagic clays whose Fe content decreases with increasing distance from the East Pacific Rise and whose biogenic component is very low. In the Peru–Chile Trench area, sediments are characterized by greenish gray to olive green, calcite-poor, organic-carbon-rich, diatomaceous muds with minor amounts of Andean volcanic ash. Continental margin sediments are similar to those in the trench area, but some areas contain sediments with significant sand fractions.

The relative importance of the terrigenous, volcanogenic, biogenic, and authigenic components in a particular area depends on several interrelated factors. In the Nazca Plate area, the Peru–Chile Trench severely restricts the dispersal of coarse-grained continental detritus. Bottom currents, including turbidity currents, probably transport coarse-grained material parallel to the continental margin or into the trench, whereas surface currents carry fine-grained suspended material out over the plate. The dispersal of Andean volcanic ash, however, depends more on the direction and magnitude of zonal winds, and apparently is not affected by bathymetric features. Consequently, Andean volcanic ash has a wider distribution to the west (up to about 500 km) than other coarse-grained terrigenous material off the coast of Peru.

In contrast, the fine detrital fraction, because of its lower settling velocity, is easily transported great distances by both winds and ocean currents. The finest continental material accumulates at very low rates on the western part of the Nazca Plate. Even so, terrigenous material makes up a moderate percentage of the clay fraction on the East Pacific Rise near 42° S (Windom 1969). In general, the low sedimentation rates over the entire Nazca Plate are due to the relatively low input of continental material from South America and the trapping of coarse-grained detritus by the trench. All means of sediment introduction are operating at very low rates in the Bauer Depression because (1) it is shielded from bottom currents originating outside the basin, (2) it is far from the continent and upwelling areas, and (3) it is near or below the CCD. The proximity of the active East Pacific Rise as well as the above factors accounts for the ferromanganoan sediments in the Bauer Depression.

Productivity in the Southeast Pacific is linked to at least three important constituents of surface sediments: organic carbon, calcium carbonate, and amorphous silica. West of South America, organic carbon values tend to decrease with increasing distance from shore, and range from 6.9 percent on the Peruvian continental margin to < 0.5 percent in the eastern part of the Peru Basin. Most other areas on the Nazca Plate have < 1-percent organic carbon. The highest values occur where the productivity is highest and the dissolved oxygen contents are lowest. On the other hand, calcite-rich sediments are found on all the oceanic ridges and along the equator but not in the Peru–Chile Trench area.

The relationship of amorphous silica content of surface sediments to productivity is similar to that of organic carbon. The quantity of siliceous microfossils delivered to the bottom should be proportional to the surface productivity. However, siliceous elements are diluted by calcareous elements along the equator and by terrigenous elements in the trench-margin area. Dissolution of silica in the water column and on the sea floor is also an important factor in reducing the silica content of the deposits (Berger 1968, 1970; Calvert 1968; Heath 1974; and Hurd 1972). Nevertheless, amorphous silica contents in the trench are somewhat higher than amorphous silica contents in the deep ocean basins (1 to 10 percent vs. < 1 percent amorphous silica).

In conclusion, the major factors which appear to determine the composition of Nazca Plate sediments are (1) the direction and speed of the dispersal mechanism and the distance from source, (2) the productivity of the surface waters, (3) the geochemical environment in the water column and on the sea floor, and (4) the topography of the sea floor.

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